

# Linux generic IRQ handling

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by Thomas Gleixner and Ingo Molnar

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# Chapter 1. Introduction

The generic interrupt handling layer is designed to provide a complete abstraction of interrupt handling for device drivers. It is able to handle all the different types of interrupt controller hardware. Device drivers use generic API functions to request, enable, disable and free interrupts. The drivers do not have to know anything about interrupt hardware details, so they can be used on different platforms without code changes.

This documentation is provided to developers who want to implement an interrupt subsystem based for their architecture, with the help of the generic IRQ handling layer.

---

# Chapter 2. Rationale

The original implementation of interrupt handling in Linux uses the `__do_IRQ()` super-handler, which is able to deal with every type of interrupt logic.

Originally, Russell King identified different types of handlers to build a quite universal set for the ARM interrupt handler implementation in Linux 2.5/2.6. He distinguished between:

- Level type
- Edge type
- Simple type

During the implementation we identified another type:

- Fast EOI type

In the SMP world of the `__do_IRQ()` super-handler another type was identified:

- Per CPU type

This split implementation of high-level IRQ handlers allows us to optimize the flow of the interrupt handling for each specific interrupt type. This reduces complexity in that particular code path and allows the optimized handling of a given type.

The original general IRQ implementation used `hw_interrupt_type` structures and their `->ack()`, `->end()` [etc.] callbacks to differentiate the flow control in the super-handler. This leads to a mix of flow logic and low-level hardware logic, and it also leads to unnecessary code duplication: for example in i386, there is an `ioapic_level_irq` and an `ioapic_edge_irq` IRQ-type which share many of the low-level details but have different flow handling.

A more natural abstraction is the clean separation of the 'irq flow' and the 'chip details'.

Analysing a couple of architecture's IRQ subsystem implementations reveals that most of them can use a generic set of 'irq flow' methods and only need to add the chip-level specific code. The separation is also valuable for (sub)architectures which need specific quirks in the IRQ flow itself but not in the chip details - and thus provides a more transparent IRQ subsystem design.

Each interrupt descriptor is assigned its own high-level flow handler, which is normally one of the generic implementations. (This high-level flow handler implementation also makes it simple to provide demultiplexing handlers which can be found in embedded platforms on various architectures.)

The separation makes the generic interrupt handling layer more flexible and extensible. For example, an (sub)architecture can use a generic IRQ-flow implementation for 'level type' interrupts and add a (sub)architecture specific 'edge type' implementation.

To make the transition to the new model easier and prevent the breakage of existing implementations, the `__do_IRQ()` super-handler is still available. This leads to a kind of duality for the time being. Over time the new model should be used in more and more architectures, as it enables smaller and cleaner IRQ subsystems. It's deprecated for three years now and about to be removed.

---

# Chapter 3. Known Bugs And Assumptions

None (knock on wood).

---

# Chapter 4. Abstraction layers

There are three main levels of abstraction in the interrupt code:

1. High-level driver API
2. High-level IRQ flow handlers
3. Chip-level hardware encapsulation

## Interrupt control flow

Each interrupt is described by an interrupt descriptor structure `irq_desc`. The interrupt is referenced by an 'unsigned int' numeric value which selects the corresponding interrupt description structure in the descriptor structures array. The descriptor structure contains status information and pointers to the interrupt flow method and the interrupt chip structure which are assigned to this interrupt.

Whenever an interrupt triggers, the low-level architecture code calls into the generic interrupt code by calling `desc->handle_irq()`. This high-level IRQ handling function only uses `desc->irq_data.chip` primitives referenced by the assigned chip descriptor structure.

## High-level Driver API

The high-level Driver API consists of following functions:

- `request_irq()`
- `free_irq()`
- `disable_irq()`
- `enable_irq()`
- `disable_irq_nosync()` (SMP only)
- `synchronize_irq()` (SMP only)
- `irq_set_irq_type()`
- `irq_set_irq_wake()`
- `irq_set_handler_data()`
- `irq_set_chip()`
- `irq_set_chip_data()`

See the autogenerated function documentation for details.

## High-level IRQ flow handlers

The generic layer provides a set of pre-defined irq-flow methods:

- `handle_level_irq`

- `handle_edge_irq`
- `handle_fasteoi_irq`
- `handle_simple_irq`
- `handle_percpu_irq`
- `handle_edge_eoi_irq`
- `handle_bad_irq`

The interrupt flow handlers (either pre-defined or architecture specific) are assigned to specific interrupts by the architecture either during bootup or during device initialization.

## Default flow implementations

### Helper functions

The helper functions call the chip primitives and are used by the default flow implementations. The following helper functions are implemented (simplified excerpt):

```
default_enable(struct irq_data *data)
{
    desc->irq_data.chip->irq_unmask(data);
}

default_disable(struct irq_data *data)
{
    if (!delay_disable(data))
        desc->irq_data.chip->irq_mask(data);
}

default_ack(struct irq_data *data)
{
    chip->irq_ack(data);
}

default_mask_ack(struct irq_data *data)
{
    if (chip->irq_mask_ack) {
        chip->irq_mask_ack(data);
    } else {
        chip->irq_mask(data);
        chip->irq_ack(data);
    }
}

noop(struct irq_data *data)
{
}
```

## Default flow handler implementations

### Default Level IRQ flow handler

`handle_level_irq` provides a generic implementation for level-triggered interrupts.

The following control flow is implemented (simplified excerpt):

```
desc->irq_data.chip->irq_mask_ack();
handle_irq_event(desc->action);
desc->irq_data.chip->irq_unmask();
```

### Default Fast EOI IRQ flow handler

`handle_fasteoi_irq` provides a generic implementation for interrupts, which only need an EOI at the end of the handler.

The following control flow is implemented (simplified excerpt):

```
handle_irq_event(desc->action);
desc->irq_data.chip->irq_eoi();
```

### Default Edge IRQ flow handler

`handle_edge_irq` provides a generic implementation for edge-triggered interrupts.

The following control flow is implemented (simplified excerpt):

```
if (desc->status & running) {
    desc->irq_data.chip->irq_mask_ack();
    desc->status |= pending | masked;
    return;
}
desc->irq_data.chip->irq_ack();
desc->status |= running;
do {
    if (desc->status & masked)
        desc->irq_data.chip->irq_unmask();
    desc->status &= ~pending;
    handle_irq_event(desc->action);
} while (status & pending);
desc->status &= ~running;
```

### Default simple IRQ flow handler

`handle_simple_irq` provides a generic implementation for simple interrupts.

Note: The simple flow handler does not call any handler/chip primitives.

The following control flow is implemented (simplified excerpt):

```
handle_irq_event(desc->action);
```

## Default per CPU flow handler

`handle_percpu_irq` provides a generic implementation for per CPU interrupts.

Per CPU interrupts are only available on SMP and the handler provides a simplified version without locking.

The following control flow is implemented (simplified excerpt):

```
if (desc->irq_data.chip->irq_ack)
    desc->irq_data.chip->irq_ack();
handle_irq_event(desc->action);
if (desc->irq_data.chip->irq_eoi)
    desc->irq_data.chip->irq_eoi();
```

## EOI Edge IRQ flow handler

`handle_edge_eoi_irq` provides an abomination of the edge handler which is solely used to tame a badly wreckaged irq controller on powerpc/cell.

## Bad IRQ flow handler

`handle_bad_irq` is used for spurious interrupts which have no real handler assigned..

## Quirks and optimizations

The generic functions are intended for 'clean' architectures and chips, which have no platform-specific IRQ handling quirks. If an architecture needs to implement quirks on the 'flow' level then it can do so by overriding the high-level irq-flow handler.

## Delayed interrupt disable

This per interrupt selectable feature, which was introduced by Russell King in the ARM interrupt implementation, does not mask an interrupt at the hardware level when `disable_irq()` is called. The interrupt is kept enabled and is masked in the flow handler when an interrupt event happens. This prevents losing edge interrupts on hardware which does not store an edge interrupt event while the interrupt is disabled at the hardware level. When an interrupt arrives while the `IRQ_DISABLED` flag is set, then the interrupt is masked at the hardware level and the `IRQ_PENDING` bit is set. When the interrupt is re-enabled by `enable_irq()` the pending bit is checked and if it is set, the interrupt is resent either via hardware or by a software resend mechanism. (It's necessary to enable `CONFIG_HARDIRQS_SW_RESEND` when you want to use the delayed interrupt disable feature and your hardware is not capable of retriggering an interrupt.) The delayed interrupt disable is not configurable.

## Chip-level hardware encapsulation

The chip-level hardware descriptor structure `irq_chip` contains all the direct chip relevant functions, which can be utilized by the irq flow implementations.

- `irq_ack()`
- `irq_mask_ack()` - Optional, recommended for performance
- `irq_mask()`
- `irq_unmask()`
- `irq_eoi()` - Optional, required for EOI flow handlers
- `irq_retrigger()` - Optional
- `irq_set_type()` - Optional
- `irq_set_wake()` - Optional

These primitives are strictly intended to mean what they say: ack means ACK, masking means masking of an IRQ line, etc. It is up to the flow handler(s) to use these basic units of low-level functionality.

---

## Chapter 5. `__do_IRQ` entry point

The original implementation `__do_IRQ()` was an alternative entry point for all types of interrupts. It no longer exists.

This handler turned out to be not suitable for all interrupt hardware and was therefore reimplemented with split functionality for edge/level/simple/percpu interrupts. This is not only a functional optimization. It also shortens code paths for interrupts.

---

# Chapter 6. Locking on SMP

The locking of chip registers is up to the architecture that defines the chip primitives. The per-irq structure is protected via desc->lock, by the generic layer.

---

# Chapter 7. Generic interrupt chip

To avoid copies of identical implementations of IRQ chips the core provides a configurable generic interrupt chip implementation. Developers should check carefully whether the generic chip fits their needs before implementing the same functionality slightly differently themselves.

## Name

`irq_gc_mask_set_bit` — Mask chip via setting bit in mask register

## Synopsis

```
void irq_gc_mask_set_bit (struct irq_data * d);
```

## Arguments

*d*   `irq_data`

## Description

Chip has a single mask register. Values of this register are cached and protected by `gc->lock`

## Name

`irq_gc_mask_clr_bit` — Mask chip via clearing bit in mask register

## Synopsis

```
void irq_gc_mask_clr_bit (struct irq_data * d);
```

## Arguments

*d*   `irq_data`

## Description

Chip has a single mask register. Values of this register are cached and protected by `gc->lock`

## Name

`irq_gc_ack_set_bit` — Ack pending interrupt via setting bit

## Synopsis

```
void irq_gc_ack_set_bit (struct irq_data * d);
```

## Arguments

*d*   `irq_data`

## Name

`irq_alloc_generic_chip` — Allocate a generic chip and initialize it

## Synopsis

```
struct irq_chip_generic * irq_alloc_generic_chip (const char *  
name, int num_ct, unsigned int irq_base, void __iomem * reg_base,  
irq_flow_handler_t handler);
```

## Arguments

<i>name</i>	Name of the irq chip
<i>num_ct</i>	Number of irq_chip_type instances associated with this
<i>irq_base</i>	Interrupt base nr for this chip
<i>reg_base</i>	Register base address (virtual)
<i>handler</i>	Default flow handler associated with this chip

## Description

Returns an initialized `irq_chip_generic` structure. The chip defaults to the primary (index 0) `irq_chip_type` and *handler*

## Name

`irq_alloc_domain_generic_chips` — Allocate generic chips for an irq domain

## Synopsis

```
int irq_alloc_domain_generic_chips (struct irq_domain * d, int
irqs_per_chip, int num_ct, const char * name, irq_flow_handler_t han-
dler, unsigned int clr, unsigned int set, enum irq_gc_flags gcflags);
```

## Arguments

<i>d</i>	irq domain for which to allocate chips
<i>irqs_per_chip</i>	Number of interrupts each chip handles
<i>num_ct</i>	Number of <code>irq_chip_type</code> instances associated with this
<i>name</i>	Name of the irq chip
<i>handler</i>	Default flow handler associated with these chips
<i>clr</i>	IRQ_* bits to clear in the mapping function
<i>set</i>	IRQ_* bits to set in the mapping function
<i>gcflags</i>	Generic chip specific setup flags

## Name

`irq_get_domain_generic_chip` — Get a pointer to the generic chip of a `hw_irq`

## Synopsis

```
struct  irq_chip_generic  *  irq_get_domain_generic_chip  (struct  
irq_domain * d, unsigned int hw_irq);
```

## Arguments

*d*            irq domain pointer

*hw\_irq*      Hardware interrupt number

## Name

`irq_setup_generic_chip` — Setup a range of interrupts with a generic chip

## Synopsis

```
void irq_setup_generic_chip (struct irq_chip_generic * gc, u32 msk, enum  
irq_gc_flags flags, unsigned int clr, unsigned int set);
```

## Arguments

<i>gc</i>	Generic irq chip holding all data
<i>msk</i>	Bitmask holding the irqs to initialize relative to <code>gc-&gt;irq_base</code>
<i>flags</i>	Flags for initialization
<i>clr</i>	IRQ_* bits to clear
<i>set</i>	IRQ_* bits to set

## Description

Set up max. 32 interrupts starting from `gc->irq_base`. Note, this initializes all interrupts to the primary `irq_chip_type` and its associated handler.

## Name

`irq_setup_alt_chip` — Switch to alternative chip

## Synopsis

```
int irq_setup_alt_chip (struct irq_data * d, unsigned int type);
```

## Arguments

*d*        `irq_data` for this interrupt

*type*    Flow type to be initialized

## Description

Only to be called from `chip->irq_set_type` callbacks.

## Name

`irq_remove_generic_chip` — Remove a chip

## Synopsis

```
void irq_remove_generic_chip (struct irq_chip_generic * gc, u32 msk,  
unsigned int clr, unsigned int set);
```

## Arguments

*gc*    Generic irq chip holding all data

*msk*   Bitmask holding the irqs to initialize relative to `gc->irq_base`

*clr*   IRQ\_\* bits to clear

*set*   IRQ\_\* bits to set

## Description

Remove up to 32 interrupts starting from `gc->irq_base`.

---

# Chapter 8. Structures

This chapter contains the autogenerated documentation of the structures which are used in the generic IRQ layer.

## Name

struct irq\_common\_data — per irq data shared by all irqchips

## Synopsis

```
struct irq_common_data {
    unsigned int state_use_accessors;
#ifdef CONFIG_NUMA
    unsigned int node;
#endif
    void * handler_data;
    struct msi_desc * msi_desc;
    cpumask_var_t affinity;
};
```

## Members

state_use_accessors	status information for irq chip functions. Use accessor functions to deal with it
node	node index useful for balancing
handler_data	per-IRQ data for the irq_chip methods
msi_desc	MSI descriptor
affinity	IRQ affinity on SMP

## Name

struct irq\_data — per irq chip data passed down to chip functions

## Synopsis

```
struct irq_data {
    u32 mask;
    unsigned int irq;
    unsigned long hwirq;
    struct irq_common_data * common;
    struct irq_chip * chip;
    struct irq_domain * domain;
#ifdef CONFIG_IRQ_DOMAIN_HIERARCHY
    struct irq_data * parent_data;
#endif
    void * chip_data;
};
```

## Members

mask	precomputed bitmask for accessing the chip registers
irq	interrupt number
hwirq	hardware interrupt number, local to the interrupt domain
common	point to data shared by all irqchips
chip	low level interrupt hardware access
domain	Interrupt translation domain; responsible for mapping between hwirq number and linux irq number.
parent_data	pointer to parent struct irq_data to support hierarchy irq_domain
chip_data	platform-specific per-chip private data for the chip methods, to allow shared chip implementations

## Name

struct irq\_chip — hardware interrupt chip descriptor

## Synopsis

```
struct irq_chip {
    const char * name;
    unsigned int (* irq_startup) (struct irq_data *data);
    void (* irq_shutdown) (struct irq_data *data);
    void (* irq_enable) (struct irq_data *data);
    void (* irq_disable) (struct irq_data *data);
    void (* irq_ack) (struct irq_data *data);
    void (* irq_mask) (struct irq_data *data);
    void (* irq_mask_ack) (struct irq_data *data);
    void (* irq_unmask) (struct irq_data *data);
    void (* irq_eoi) (struct irq_data *data);
    int (* irq_set_affinity) (struct irq_data *data, const struct cpumask *dest, bool);
    int (* irq_retrigger) (struct irq_data *data);
    int (* irq_set_type) (struct irq_data *data, unsigned int flow_type);
    int (* irq_set_wake) (struct irq_data *data, unsigned int on);
    void (* irq_bus_lock) (struct irq_data *data);
    void (* irq_bus_sync_unlock) (struct irq_data *data);
    void (* irq_cpu_online) (struct irq_data *data);
    void (* irq_cpu_offline) (struct irq_data *data);
    void (* irq_suspend) (struct irq_data *data);
    void (* irq_resume) (struct irq_data *data);
    void (* irq_pm_shutdown) (struct irq_data *data);
    void (* irq_calc_mask) (struct irq_data *data);
    void (* irq_print_chip) (struct irq_data *data, struct seq_file *p);
    int (* irq_request_resources) (struct irq_data *data);
    void (* irq_release_resources) (struct irq_data *data);
    void (* irq_compose_msi_msg) (struct irq_data *data, struct msi_msg *msg);
    void (* irq_write_msi_msg) (struct irq_data *data, struct msi_msg *msg);
    int (* irq_get_irqchip_state) (struct irq_data *data, enum irqchip_irq_state which);
    int (* irq_set_irqchip_state) (struct irq_data *data, enum irqchip_irq_state which, int val);
    int (* irq_set_vcpu_affinity) (struct irq_data *data, void *vcpu_info);
    unsigned long flags;
};
```

## Members

name	name for /proc/interrupts
irq_startup	start up the interrupt (defaults to ->enable if NULL)
irq_shutdown	shut down the interrupt (defaults to ->disable if NULL)
irq_enable	enable the interrupt (defaults to chip->unmask if NULL)
irq_disable	disable the interrupt
irq_ack	start of a new interrupt

<code>irq_mask</code>	mask an interrupt source
<code>irq_mask_ack</code>	ack and mask an interrupt source
<code>irq_unmask</code>	unmask an interrupt source
<code>irq_eoi</code>	end of interrupt
<code>irq_set_affinity</code>	set the CPU affinity on SMP machines
<code>irq_retrigger</code>	resend an IRQ to the CPU
<code>irq_set_type</code>	set the flow type ( <code>IRQ_TYPE_LEVEL</code> /etc.) of an IRQ
<code>irq_set_wake</code>	enable/disable power-management wake-on of an IRQ
<code>irq_bus_lock</code>	function to lock access to slow bus (i2c) chips
<code>irq_bus_sync_unlock</code>	function to sync and unlock slow bus (i2c) chips
<code>irq_cpu_online</code>	configure an interrupt source for a secondary CPU
<code>irq_cpu_offline</code>	un-configure an interrupt source for a secondary CPU
<code>irq_suspend</code>	function called from core code on suspend once per chip, when one or more interrupts are installed
<code>irq_resume</code>	function called from core code on resume once per chip, when one or more interrupts are installed
<code>irq_pm_shutdown</code>	function called from core code on shutdown once per chip
<code>irq_calc_mask</code>	Optional function to set <code>irq_data.mask</code> for special cases
<code>irq_print_chip</code>	optional to print special chip info in <code>show_interrupts</code>
<code>irq_request_resources</code>	optional to request resources before calling any other callback related to this irq
<code>irq_release_resources</code>	optional to release resources acquired with <code>irq_request_resources</code>
<code>irq_compose_msi_msg</code>	optional to compose message content for MSI
<code>irq_write_msi_msg</code>	optional to write message content for MSI
<code>irq_get_irqchip_state</code>	return the internal state of an interrupt
<code>irq_set_irqchip_state</code>	set the internal state of a interrupt
<code>irq_set_vcpu_affinity</code>	optional to target a vCPU in a virtual machine
<code>flags</code>	chip specific flags

## Name

struct irq\_chip\_regs — register offsets for struct irq\_gci

## Synopsis

```
struct irq_chip_regs {  
    unsigned long enable;  
    unsigned long disable;  
    unsigned long mask;  
    unsigned long ack;  
    unsigned long eoi;  
    unsigned long type;  
    unsigned long polarity;  
};
```

## Members

enable	Enable register offset to reg_base
disable	Disable register offset to reg_base
mask	Mask register offset to reg_base
ack	Ack register offset to reg_base
eoi	Eoi register offset to reg_base
type	Type configuration register offset to reg_base
polarity	Polarity configuration register offset to reg_base

## Name

struct irq\_chip\_type — Generic interrupt chip instance for a flow type

## Synopsis

```
struct irq_chip_type {
    struct irq_chip chip;
    struct irq_chip_regs regs;
    irq_flow_handler_t handler;
    u32 type;
    u32 mask_cache_priv;
    u32 * mask_cache;
};
```

## Members

chip	The real interrupt chip which provides the callbacks
regs	Register offsets for this chip
handler	Flow handler associated with this chip
type	Chip can handle these flow types
mask_cache_priv	Cached mask register private to the chip type
mask_cache	Pointer to cached mask register

## Description

A `irq_generic_chip` can have several instances of `irq_chip_type` when it requires different functions and register offsets for different flow types.

## Name

struct irq\_chip\_generic — Generic irq chip data structure

## Synopsis

```
struct irq_chip_generic {
    raw_spinlock_t lock;
    void __iomem * reg_base;
    u32 (* reg_readl) (void __iomem *addr);
    void (* reg_writel) (u32 val, void __iomem *addr);
    void (* suspend) (struct irq_chip_generic *gc);
    void (* resume) (struct irq_chip_generic *gc);
    unsigned int irq_base;
    unsigned int irq_cnt;
    u32 mask_cache;
    u32 type_cache;
    u32 polarity_cache;
    u32 wake_enabled;
    u32 wake_active;
    unsigned int num_ct;
    void * private;
    unsigned long installed;
    unsigned long unused;
    struct irq_domain * domain;
    struct list_head list;
    struct irq_chip_type chip_types[0];
};
```

## Members

lock	Lock to protect register and cache data access
reg_base	Register base address (virtual)
reg_readl	Alternate I/O accessor (defaults to readl if NULL)
reg_writel	Alternate I/O accessor (defaults to writel if NULL)
suspend	Function called from core code on suspend once per chip; can be useful instead of irq_chip::suspend to handle chip details even when no interrupts are in use
resume	Function called from core code on resume once per chip;
irq_base	Interrupt base nr for this chip
irq_cnt	Number of interrupts handled by this chip
mask_cache	Cached mask register shared between all chip types
type_cache	Cached type register
polarity_cache	Cached polarity register
wake_enabled	Interrupt can wakeup from suspend

wake_active	Interrupt is marked as an wakeup from suspend source
num_ct	Number of available irq_chip_type instances (usually 1)
private	Private data for non generic chip callbacks
installed	bitfield to denote installed interrupts
unused	bitfield to denote unused interrupts
domain	irq domain pointer
list	List head for keeping track of instances
chip_types[0]	Array of interrupt irq_chip_types

## can be useful instead of irq\_chip

:suspend to handle chip details even when no interrupts are in use

## Description

Note, that irq\_chip\_generic can have multiple irq\_chip\_type implementations which can be associated to a particular irq line of an irq\_chip\_generic instance. That allows to share and protect state in an irq\_chip\_generic instance when we need to implement different flow mechanisms (level/edge) for it.

## Name

enum irq\_gc\_flags — Initialization flags for generic irq chips

## Synopsis

```
enum irq_gc_flags {  
    IRQ_GC_INIT_MASK_CACHE,  
    IRQ_GC_INIT_NESTED_LOCK,  
    IRQ_GC_MASK_CACHE_PER_TYPE,  
    IRQ_GC_NO_MASK,  
    IRQ_GC_BE_IO  
};
```

## Constants

IRQ_GC_INIT_MASK_CACHE	Initialize the mask_cache by reading mask reg
IRQ_GC_INIT_NESTED_LOCK	Set the lock class of the irqs to nested for irq chips which need to call irq_set_wake on the parent irq. Usually GPIO implementations
IRQ_GC_MASK_CACHE_PER_TYPE	Mask cache is chip type private
IRQ_GC_NO_MASK	Do not calculate irq_data->mask
IRQ_GC_BE_IO	Use big-endian register accesses (default: LE)

## Name

struct irqaction — per interrupt action descriptor

## Synopsis

```
struct irqaction {
    irq_handler_t handler;
    void * dev_id;
    void __percpu * percpu_dev_id;
    struct irqaction * next;
    irq_handler_t thread_fn;
    struct task_struct * thread;
    struct irqaction * secondary;
    unsigned int irq;
    unsigned int flags;
    unsigned long thread_flags;
    unsigned long thread_mask;
    const char * name;
    struct proc_dir_entry * dir;
};
```

## Members

handler	interrupt handler function
dev_id	cookie to identify the device
percpu_dev_id	cookie to identify the device
next	pointer to the next irqaction for shared interrupts
thread_fn	interrupt handler function for threaded interrupts
thread	thread pointer for threaded interrupts
secondary	pointer to secondary irqaction (force threading)
irq	interrupt number
flags	flags (see IRQF_* above)
thread_flags	flags related to <i>thread</i>
thread_mask	bitmask for keeping track of <i>thread</i> activity
name	name of the device
dir	pointer to the proc/irq/NN/name entry

## Name

struct irq\_affinity\_notify — context for notification of IRQ affinity changes

## Synopsis

```
struct irq_affinity_notify {
    unsigned int irq;
    struct kref kref;
    struct work_struct work;
    void (* notify) (struct irq_affinity_notify *, const cpumask_t *mask);
    void (* release) (struct kref *ref);
};
```

## Members

irq	Interrupt to which notification applies
kref	Reference count, for internal use
work	Work item, for internal use
notify	Function to be called on change. This will be called in process context.
release	Function to be called on release. This will be called in process context. Once registered, the structure must only be freed when this function is called or later.

## Name

`irq_set_affinity` — Set the irq affinity of a given irq

## Synopsis

```
int irq_set_affinity (unsigned int irq, const struct cpumask * cpumask);
```

## Arguments

*irq*            Interrupt to set affinity

*cpumask*    cpumask

## Description

Fails if cpumask does not contain an online CPU

## Name

`irq_force_affinity` — Force the irq affinity of a given irq

## Synopsis

```
int irq_force_affinity (unsigned int irq, const struct cpumask *  
cpumask);
```

## Arguments

*irq*            Interrupt to set affinity

*cpumask*    cpumask

## Description

Same as `irq_set_affinity`, but without checking the mask against online cpus.

Solely for low level cpu hotplug code, where we need to make per cpu interrupts affine before the cpu becomes online.

---

# Chapter 9. Public Functions Provided

This chapter contains the autogenerated documentation of the kernel API functions which are exported.

## Name

synchronize\_hardirq — wait for pending hard IRQ handlers (on other CPUs)

## Synopsis

```
bool synchronize_hardirq (unsigned int irq);
```

## Arguments

*irq* interrupt number to wait for

## Description

This function waits for any pending hard IRQ handlers for this interrupt to complete before returning. If you use this function while holding a resource the IRQ handler may need you will deadlock. It does not take associated threaded handlers into account.

Do not use this for shutdown scenarios where you must be sure that all parts (hardirq and threaded handler) have completed.

## Returns

false if a threaded handler is active.

This function may be called - with care - from IRQ context.

## Name

`synchronize_irq` — wait for pending IRQ handlers (on other CPUs)

## Synopsis

```
void synchronize_irq (unsigned int irq);
```

## Arguments

*irq* interrupt number to wait for

## Description

This function waits for any pending IRQ handlers for this interrupt to complete before returning. If you use this function while holding a resource the IRQ handler may need you will deadlock.

This function may be called - with care - from IRQ context.

## Name

`irq_set_affinity_notifier` — control notification of IRQ affinity changes

## Synopsis

```
int    irq_set_affinity_notifier    (unsigned    int    irq,    struct
irq_affinity_notify * notify);
```

## Arguments

*irq* Interrupt for which to enable/disable notification

*notify* Context for notification, or NULL to disable notification. Function pointers must be initialised; the other fields will be initialised by this function.

## Description

Must be called in process context. Notification may only be enabled after the IRQ is allocated and must be disabled before the IRQ is freed using `free_irq`.

## Name

`irq_set_vcpu_affinity` — Set vcpu affinity for the interrupt

## Synopsis

```
int irq_set_vcpu_affinity (unsigned int irq, void * vcpu_info);
```

## Arguments

*irq*                    interrupt number to set affinity

*vcpu\_info*    vCPU specific data

## Description

This function uses the vCPU specific data to set the vCPU affinity for an irq. The vCPU specific data is passed from outside, such as KVM. One example code path is as below: KVM -> IOMMU -> `irq_set_vcpu_affinity`.

## Name

`disable_irq_nosync` — disable an irq without waiting

## Synopsis

```
void disable_irq_nosync (unsigned int irq);
```

## Arguments

*irq* Interrupt to disable

## Description

Disable the selected interrupt line. Disables and Enables are nested. Unlike `disable_irq`, this function does not ensure existing instances of the IRQ handler have completed before returning.

This function may be called from IRQ context.

## Name

`disable_irq` — disable an irq and wait for completion

## Synopsis

```
void disable_irq (unsigned int irq);
```

## Arguments

*irq* Interrupt to disable

## Description

Disable the selected interrupt line. Enables and Disables are nested. This function waits for any pending IRQ handlers for this interrupt to complete before returning. If you use this function while holding a resource the IRQ handler may need you will deadlock.

This function may be called - with care - from IRQ context.

## Name

`disable_hardirq` — disables an irq and waits for hardirq completion

## Synopsis

```
bool disable_hardirq (unsigned int irq);
```

## Arguments

*irq* Interrupt to disable

## Description

Disable the selected interrupt line. Enables and Disables are nested. This function waits for any pending hard IRQ handlers for this interrupt to complete before returning. If you use this function while holding a resource the hard IRQ handler may need you will deadlock.

When used to optimistically disable an interrupt from atomic context the return value must be checked.

## Returns

false if a threaded handler is active.

This function may be called - with care - from IRQ context.

## Name

`enable_irq` — enable handling of an irq

## Synopsis

```
void enable_irq (unsigned int irq);
```

## Arguments

*irq* Interrupt to enable

## Description

Undoes the effect of one call to `disable_irq`. If this matches the last disable, processing of interrupts on this IRQ line is re-enabled.

This function may be called from IRQ context only when `desc->irq_data.chip->bus_lock` and `desc->chip->bus_sync_unlock` are NULL !

## Name

`irq_set_irq_wake` — control irq power management wakeup

## Synopsis

```
int irq_set_irq_wake (unsigned int irq, unsigned int on);
```

## Arguments

*irq*    interrupt to control

*on*    enable/disable power management wakeup

## Description

Enable/disable power management wakeup mode, which is disabled by default. Enables and disables must match, just as they match for non-wakeup mode support.

Wakeup mode lets this IRQ wake the system from sleep states like “suspend to RAM”.

## Name

`irq_wake_thread` — wake the irq thread for the action identified by `dev_id`

## Synopsis

```
void irq_wake_thread (unsigned int irq, void * dev_id);
```

## Arguments

*irq*      Interrupt line

*dev\_id*   Device identity for which the thread should be woken

## Name

`setup_irq` — setup an interrupt

## Synopsis

```
int setup_irq (unsigned int irq, struct irqaction * act);
```

## Arguments

*irq*    Interrupt line to setup

*act*    irqaction for the interrupt

## Description

Used to statically setup interrupts in the early boot process.

## Name

`remove_irq` — free an interrupt

## Synopsis

```
void remove_irq (unsigned int irq, struct irqaction * act);
```

## Arguments

*irq*    Interrupt line to free

*act*    irqaction for the interrupt

## Description

Used to remove interrupts statically setup by the early boot process.

## Name

`free_irq` — free an interrupt allocated with `request_irq`

## Synopsis

```
void free_irq (unsigned int irq, void * dev_id);
```

## Arguments

*irq*        Interrupt line to free

*dev\_id*    Device identity to free

## Description

Remove an interrupt handler. The handler is removed and if the interrupt line is no longer in use by any driver it is disabled. On a shared IRQ the caller must ensure the interrupt is disabled on the card it drives before calling this function. The function does not return until any executing interrupts for this IRQ have completed.

This function must not be called from interrupt context.

## Name

`request_threaded_irq` — allocate an interrupt line

## Synopsis

```
int request_threaded_irq (unsigned int irq, irq_handler_t handler,
irq_handler_t thread_fn, unsigned long irqflags, const char * devname,
void * dev_id);
```

## Arguments

<i>irq</i>	Interrupt line to allocate
<i>handler</i>	Function to be called when the IRQ occurs. Primary handler for threaded interrupts If NULL and <i>thread_fn</i> != NULL the default primary handler is installed
<i>thread_fn</i>	Function called from the irq handler thread If NULL, no irq thread is created
<i>irqflags</i>	Interrupt type flags
<i>devname</i>	An ascii name for the claiming device
<i>dev_id</i>	A cookie passed back to the handler function

## Description

This call allocates interrupt resources and enables the interrupt line and IRQ handling. From the point this call is made your handler function may be invoked. Since your handler function must clear any interrupt the board raises, you must take care both to initialise your hardware and to set up the interrupt handler in the right order.

If you want to set up a threaded irq handler for your device then you need to supply *handler* and *thread\_fn*. *handler* is still called in hard interrupt context and has to check whether the interrupt originates from the device. If yes it needs to disable the interrupt on the device and return `IRQ_WAKE_THREAD` which will wake up the handler thread and run *thread\_fn*. This split handler design is necessary to support shared interrupts.

*Dev\_id* must be globally unique. Normally the address of the device data structure is used as the cookie. Since the handler receives this value it makes sense to use it.

If your interrupt is shared you must pass a non NULL *dev\_id* as this is required when freeing the interrupt.

## Flags

`IRQF_SHARED` Interrupt is shared `IRQF_TRIGGER_*` Specify active edge(s) or level

## Name

`request_any_context_irq` — allocate an interrupt line

## Synopsis

```
int request_any_context_irq (unsigned int irq, irq_handler_t handler,
unsigned long flags, const char * name, void * dev_id);
```

## Arguments

<i>irq</i>	Interrupt line to allocate
<i>handler</i>	Function to be called when the IRQ occurs. Threaded handler for threaded interrupts.
<i>flags</i>	Interrupt type flags
<i>name</i>	An ascii name for the claiming device
<i>dev_id</i>	A cookie passed back to the handler function

## Description

This call allocates interrupt resources and enables the interrupt line and IRQ handling. It selects either a hardirq or threaded handling method depending on the context.

On failure, it returns a negative value. On success, it returns either `IRQC_IS_HARDIRQ` or `IRQC_IS_NESTED`.

## Name

`free_percpu_irq` — free an interrupt allocated with `request_percpu_irq`

## Synopsis

```
void free_percpu_irq (unsigned int irq, void __percpu * dev_id);
```

## Arguments

*irq*        Interrupt line to free

*dev\_id*    Device identity to free

## Description

Remove a percpu interrupt handler. The handler is removed, but the interrupt line is not disabled. This must be done on each CPU before calling this function. The function does not return until any executing interrupts for this IRQ have completed.

This function must not be called from interrupt context.

## Name

`request_percpu_irq` — allocate a percpu interrupt line

## Synopsis

```
int request_percpu_irq (unsigned int irq, irq_handler_t handler, const  
char * devname, void __percpu * dev_id);
```

## Arguments

*irq*            Interrupt line to allocate

*handler*      Function to be called when the IRQ occurs.

*devname*      An ascii name for the claiming device

*dev\_id*       A percpu cookie passed back to the handler function

## Description

This call allocates interrupt resources and enables the interrupt on the local CPU. If the interrupt is supposed to be enabled on other CPUs, it has to be done on each CPU using `enable_percpu_irq`.

`Dev_id` must be globally unique. It is a per-cpu variable, and the handler gets called with the interrupted CPU's instance of that variable.

## Name

`irq_get_irqchip_state` — returns the irqchip state of a interrupt.

## Synopsis

```
int irq_get_irqchip_state (unsigned int irq, enum irqchip_irq_state
which, bool * state);
```

## Arguments

*irq*      Interrupt line that is forwarded to a VM

*which*   One of IRQCHIP\_STATE\_\* the caller wants to know about

*state*    a pointer to a boolean where the state is to be storeed

## Description

This call snapshots the internal irqchip state of an interrupt, returning into *state* the bit corresponding to stage *which*

This function should be called with preemption disabled if the interrupt controller has per-cpu registers.

## Name

`irq_set_irqchip_state` — set the state of a forwarded interrupt.

## Synopsis

```
int irq_set_irqchip_state (unsigned int irq, enum irqchip_irq_state
which, bool val);
```

## Arguments

*irq*      Interrupt line that is forwarded to a VM

*which*    State to be restored (one of IRQCHIP\_STATE\_\*)

*val*      Value corresponding to *which*

## Description

This call sets the internal irqchip state of an interrupt, depending on the value of *which*.

This function should be called with preemption disabled if the interrupt controller has per-cpu registers.

## Name

`irq_set_chip` — set the irq chip for an irq

## Synopsis

```
int irq_set_chip (unsigned int irq, struct irq_chip * chip);
```

## Arguments

*irq*    irq number

*chip*   pointer to irq chip description structure

## Name

`irq_set_irq_type` — set the irq trigger type for an irq

## Synopsis

```
int irq_set_irq_type (unsigned int irq, unsigned int type);
```

## Arguments

*irq*    irq number

*type*   IRQ\_TYPE\_{LEVEL,EDGE}\_\* value - see include/linux/irq.h

## Name

`irq_set_handler_data` — set irq handler data for an irq

## Synopsis

```
int irq_set_handler_data (unsigned int irq, void * data);
```

## Arguments

*irq*    Interrupt number

*data*   Pointer to interrupt specific data

## Description

Set the hardware irq controller data for an irq

## Name

`irq_set_chip_data` — set irq chip data for an irq

## Synopsis

```
int irq_set_chip_data (unsigned int irq, void * data);
```

## Arguments

*irq*     Interrupt number

*data*   Pointer to chip specific data

## Description

Set the hardware irq chip data for an irq

## Name

`handle_simple_irq` — Simple and software-decoded IRQs.

## Synopsis

```
void handle_simple_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Simple interrupts are either sent from a demultiplexing interrupt handler or come from hardware, where no interrupt hardware control is necessary.

## Note

The caller is expected to handle the ack, clear, mask and unmask issues if necessary.

## Name

`handle_untracked_irq` — Simple and software-decoded IRQs.

## Synopsis

```
void handle_untracked_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Untracked interrupts are sent from a demultiplexing interrupt handler when the demultiplexer does not know which device in its multiplexed irq domain generated the interrupt. IRQ's handled through here are not subjected to stats tracking, randomness, or spurious interrupt detection.

## Note

Like `handle_simple_irq`, the caller is expected to handle the ack, clear, mask and unmask issues if necessary.

## Name

`handle_level_irq` — Level type irq handler

## Synopsis

```
void handle_level_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Level type interrupts are active as long as the hardware line has the active level. This may require to mask the interrupt and unmask it after the associated handler has acknowledged the device, so the interrupt line is back to inactive.

## Name

`handle_fasteoi_irq` — irq handler for transparent controllers

## Synopsis

```
void handle_fasteoi_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Only a single callback will be issued to the chip

an `->eoi` call when the interrupt has been serviced. This enables support for modern forms of interrupt handlers, which handle the flow details in hardware, transparently.

## Name

`handle_edge_irq` — edge type IRQ handler

## Synopsis

```
void handle_edge_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Interrupt occurs on the falling and/or rising edge of a hardware signal. The occurrence is latched into the irq controller hardware and must be acked in order to be reenabled. After the ack another interrupt can happen on the same source even before the first one is handled by the associated event handler. If this happens it might be necessary to disable (mask) the interrupt depending on the controller hardware. This requires to reenale the interrupt inside of the loop which handles the interrupts which have arrived while the handler was running. If all pending interrupts are handled, the loop is left.

## Name

`irq_chip_ack_parent` — Acknowledge the parent interrupt

## Synopsis

```
void irq_chip_ack_parent (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Name

`irq_chip_mask_parent` — Mask the parent interrupt

## Synopsis

```
void irq_chip_mask_parent (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Name

`irq_chip_unmask_parent` — Unmask the parent interrupt

## Synopsis

```
void irq_chip_unmask_parent (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Name

`irq_chip_eoi_parent` — Invoke EOI on the parent interrupt

## Synopsis

```
void irq_chip_eoi_parent (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Name

`irq_chip_set_type_parent` — Set IRQ type on the parent interrupt

## Synopsis

```
int irq_chip_set_type_parent (struct irq_data * data, unsigned int
type);
```

## Arguments

*data* Pointer to interrupt specific data

*type* `IRQ_TYPE_{LEVEL,EDGE}_*` value - see `include/linux/irq.h`

## Description

Conditional, as the underlying parent chip might not implement it.

---

# Chapter 10. Internal Functions Provided

This chapter contains the autogenerated documentation of the internal functions.

## Name

`__handle_domain_irq` — Invoke the handler for a HW irq belonging to a domain

## Synopsis

```
int __handle_domain_irq (struct irq_domain * domain, unsigned int hwirq,  
    bool lookup, struct pt_regs * regs);
```

## Arguments

*domain*    The domain where to perform the lookup

*hwirq*    The HW irq number to convert to a logical one

*lookup*    Whether to perform the domain lookup or not

*regs*      Register file coming from the low-level handling code

## Returns

0 on success, or -EINVAL if conversion has failed

## Name

`irq_get_next_irq` — get next allocated irq number

## Synopsis

```
unsigned int irq_get_next_irq (unsigned int offset);
```

## Arguments

*offset* where to start the search

## Description

Returns next irq number after offset or `nr_irqs` if none is found.

## Name

kstat\_irqs\_cpu — Get the statistics for an interrupt on a cpu

## Synopsis

```
unsigned int kstat_irqs_cpu (unsigned int irq, int cpu);
```

## Arguments

*irq*    The interrupt number

*cpu*    The cpu number

## Description

Returns the sum of interrupt counts on *cpu* since boot for *irq*. The caller must ensure that the interrupt is not removed concurrently.

## Name

kstat\_irqs — Get the statistics for an interrupt

## Synopsis

```
unsigned int kstat_irqs (unsigned int irq);
```

## Arguments

*irq* The interrupt number

## Description

Returns the sum of interrupt counts on all cpus since boot for *irq*. The caller must ensure that the interrupt is not removed concurrently.

## Name

`kstat_irqs_usr` — Get the statistics for an interrupt

## Synopsis

```
unsigned int kstat_irqs_usr (unsigned int irq);
```

## Arguments

*irq* The interrupt number

## Description

Returns the sum of interrupt counts on all cpus since boot for *irq*. Contrary to `kstat_irqs` this can be called from any preemptible context. It's protected against concurrent removal of an interrupt descriptor when sparse irqs are enabled.

## Name

kernel/irq/handle.c — Document generation inconsistency

## Oops

### Warning

The template for this document tried to insert the structured comment from the file `kernel/irq/handle.c` at this point, but none was found. This dummy section is inserted to allow generation to continue.

## Name

`irq_set_msi_desc_off` — set MSI descriptor data for an irq at offset

## Synopsis

```
int irq_set_msi_desc_off (unsigned int irq_base, unsigned int  
irq_offset, struct msi_desc * entry);
```

## Arguments

<i>irq_base</i>	Interrupt number base
<i>irq_offset</i>	Interrupt number offset
<i>entry</i>	Pointer to MSI descriptor data

## Description

Set the MSI descriptor entry for an irq at offset

## Name

`irq_set_msi_desc` — set MSI descriptor data for an irq

## Synopsis

```
int irq_set_msi_desc (unsigned int irq, struct msi_desc * entry);
```

## Arguments

*irq*      Interrupt number

*entry*    Pointer to MSI descriptor data

## Description

Set the MSI descriptor entry for an irq

## Name

`irq_disable` — Mark interrupt disabled

## Synopsis

```
void irq_disable (struct irq_desc * desc);
```

## Arguments

*desc*    irq descriptor which should be disabled

## Description

If the chip does not implement the `irq_disable` callback, we use a lazy disable approach. That means we mark the interrupt disabled, but leave the hardware unmasked. That's an optimization because we avoid the hardware access for the common case where no interrupt happens after we marked it disabled. If an interrupt happens, then the interrupt flow handler masks the line at the hardware level and marks it pending.

If the interrupt chip does not implement the `irq_disable` callback, a driver can disable the lazy approach for a particular irq line by calling '`irq_set_status_flags(irq, IRQ_DISABLE_UNLAZY)`'. This can be used for devices which cannot disable the interrupt at the device level under certain circumstances and have to use `disable_irq[_nosync]` instead.

## Name

`handle_edge_eoi_irq` — edge eoi type IRQ handler

## Synopsis

```
void handle_edge_eoi_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Similar as the above `handle_edge_irq`, but using eoi and w/o the mask/unmask logic.

## Name

`handle_percpu_irq` — Per CPU local irq handler

## Synopsis

```
void handle_percpu_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Per CPU interrupts on SMP machines without locking requirements

## Name

`handle_percpu_devid_irq` — Per CPU local irq handler with per cpu dev ids

## Synopsis

```
void handle_percpu_devid_irq (struct irq_desc * desc);
```

## Arguments

*desc* the interrupt description structure for this irq

## Description

Per CPU interrupts on SMP machines without locking requirements. Same as `handle_percpu_irq` above but with the following extras:

action->percpu\_dev\_id is a pointer to percpu variables which contain the real device id for the cpu on which this handler is called

## Name

`irq_cpu_online` — Invoke all `irq_cpu_online` functions.

## Synopsis

```
void irq_cpu_online ( void );
```

## Arguments

*void* no arguments

## Description

Iterate through all `irqs` and invoke the `chip.irq_cpu_online` for each.

## Name

`irq_cpu_offline` — Invoke all `irq_cpu_offline` functions.

## Synopsis

```
void irq_cpu_offline ( void );
```

## Arguments

*void* no arguments

## Description

Iterate through all `irqs` and invoke the `chip.irq_cpu_offline` for each.

## Name

`irq_chip_enable_parent` — Enable the parent interrupt (defaults to unmask if NULL)

## Synopsis

```
void irq_chip_enable_parent (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Name

`irq_chip_disable_parent` — Disable the parent interrupt (defaults to mask if NULL)

## Synopsis

```
void irq_chip_disable_parent (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Name

`irq_chip_set_affinity_parent` — Set affinity on the parent interrupt

## Synopsis

```
int irq_chip_set_affinity_parent (struct irq_data * data, const struct  
cpumask * dest, bool force);
```

## Arguments

*data*     Pointer to interrupt specific data

*dest*     The affinity mask to set

*force*    Flag to enforce setting (disable online checks)

## Description

Conditinal, as the underlying parent chip might not implement it.

## Name

`irq_chip_retrigger_hierarchy` — Retrigger an interrupt in hardware

## Synopsis

```
int irq_chip_retrigger_hierarchy (struct irq_data * data);
```

## Arguments

*data*    Pointer to interrupt specific data

## Description

Iterate through the domain hierarchy of the interrupt and check whether a hw retrigger function exists. If yes, invoke it.

## Name

`irq_chip_set_vcpu_affinity_parent` — Set vcpu affinity on the parent interrupt

## Synopsis

```
int irq_chip_set_vcpu_affinity_parent (struct irq_data * data, void *  
vcpu_info);
```

## Arguments

*data*            Pointer to interrupt specific data

*vcpu\_info*    The vcpu affinity information

## Name

`irq_chip_set_wake_parent` — Set/reset wake-up on the parent interrupt

## Synopsis

```
int irq_chip_set_wake_parent (struct irq_data * data, unsigned int on);
```

## Arguments

*data*    Pointer to interrupt specific data

*on*      Whether to set or reset the wake-up capability of this irq

## Description

Conditional, as the underlying parent chip might not implement it.

## Name

`irq_chip_compose_msi_msg` — Compose msi message for a irq chip

## Synopsis

```
int irq_chip_compose_msi_msg (struct irq_data * data, struct msi_msg
* msg);
```

## Arguments

*data*    Pointer to interrupt specific data

*msg*     Pointer to the MSI message

## Description

For hierarchical domains we find the first chip in the hierarchy which implements the `irq_compose_msi_msg` callback. For non hierarchical we use the top level chip.

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# Chapter 11. Credits

The following people have contributed to this document:

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